AN INVESTIGATION OF INSPECTOR ACCURACY AT THE TASK OF RECOGNIZING RANDOM NUMBERS

by

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B. S. Kansas State University, 1961

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1964

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INTRODUCTION

The purpose of this research was to investigate a technique which may be useful in evaluating the accuracy of industrial inspectors at the task of inspection of attributes. This technique utilized a method of visual identification and notation of randomly originated one-digit numbers, presented for attributes inspection at both random time intervals and fixed time intervals.

Several sources (26) in the literature of industrial inspection advocate 100 percent inspection of attributes as an absolute criterion for assuring complete control over a manufacturing process and for separating satisfactory product from unsatisfactory product. The two methods generally utilized (30) for separating product of acceptable quality from that of unacceptable quality are sampling inspection and screening inspection. Sampling inspection is the inspection or examination of a sample of randomly selected items from a larger group or lot. Each unit of the lot sample is individually scrutinized and the entire lot is accepted or rejected on the basis of inspection obtained from the sample. Another sampling inspection procedure is that in which the inspector is required to examine a sequence of items. This is known as continuous sampling inspection. The items are individually inspected in the order of their manufacture or process. Since each item of product is inspected individually in sampling inspection procedures, this method of separating product is much like the second method, that of screening. Screening inspection is referred to as sorting or 100 percent

inspection and is that type of inspection where again each and every unit of product is inspected.

Screening inspection, sampling inspection of lot samples and continuous sampling procedures are all complementary because these techniques involve examination of each unit of product, whether the product is moving by the inspector at some fixed or random rate or whether the inspector himself is selecting each unit at a fixed or random interval between units.

Information obtained from a number of aerospace firms, aircraft manufacturers, and electronics producers (33, 34, 35, 36, 37) indicates that 100 percent inspection is used regularly to assure conformance to specifications. It was further noted that these uses are most frequently found when inspections are of an attributes nature, such as those involving the numerical condition of a monitoring device, a size number, a serial number, or some other inspection of a "go or no-go" type. One source (31) advocates the use of 100 percent inspection on short-run jobs in place of sampling inspection and also where continued sorting or screening is needed to monitor a process or to bring product to an acceptable quality level.

The technique of 100 percent inspection of attributes is widely used in industry to assure quality of product. The accuracy of this technique has been subject to question and has been determined to be different at different tasks. A technique for the determination of this accuracy is the subject of this thesis.

LITERATURE REVIEW - PREVIOUS EXPERIMENTS IN INSPECTOR ACCURACY

One-hundred percent inspection of attributes is defined by the Department of Defense as

> that type of inspection in which each item of product is inspected....the unit of product being classified simply as defective or non-defective with respect to a given requirement or set of requirements (30).

This type of inspection technique is used to review and classify product into categories of acceptable or unacceptable during many inspection tasks in industry today.

When the product is to be judged acceptable or non-acceptable by the use of the sampling inspection technique, a representative sample of product is taken at random from an inspection lot. Then, when scrutinized for attributes acceptability, the product is checked as to whether or not it has specified characteristics, such as a certain imperfection, correct assembly of all components, proper size number or serial number. These decisions are made on each unit of product in the sample. Thus the sample is 100 percent inspected.

When the product is subjected to screening or sorting, this decision to accept or reject is made on each and every unit of the inspection lot. The entire lot is 100 percent inspected.

Another of the common uses of 100 percent inspection of attributes is in continuous sampling plans (17) where it is used to eliminate the need for inspection lot information. This technique of sampling was first introduced by H. F. Dodge (11) in 1943. Continuous sampling inspection procedure begins with the inspection of each unit of product in the sequence of

production until i successive conforming units are inspected. As soon as this qualification is met, a sampling plan is used until a defective unit is found. Then 100 percent inspection is again resumed until i defect-free units have again been found. Several modifications of this plan have been developed.

In addition to the literature cited above, there are available theories and principles for calculating the risk of accepting defective lots involved when using these plans. These data provide for statistical analyses and for the construction of operating characteristic curves. However, nowhere do we find any indication of a formally defined method to determine the accuracy of the inspectors who do the actual 100 percent inspection work.

The subject of a formal method to determine the accuracy of inspectors during the task of 100 percent inspection has been subject to discussion and experimentation in recent years. Industrial and quality control engineers, and applied and experimental psychologists have studied this problem in some detail. Their results have shown several differences in the accuracy of inspectors during various inspection activities.

In an experiment to determine the accuracy of inspectors during the inspection of wheat samples, psychologist Adams (1) notes that

> ...the reliability of both initial and repeat estimates of grade and subclass of the composite sample, when evaluated in relation to the grain standards, revealed that 40 percent of the initial estimated placed the sample improperly, and that 42.5 percent of the repeat estimated changed the grade and/or subclass of the sample, while 20.5 percent of the samples were evaluated improperly on grade and/or subclass on both occasions.

This 20.5 percent improper evaluation of the samples on two successive identical experiments gives the result that the inspectors here were only 79.5 percent accurate at this task.

Grether (16) determined that the accuracy of pilots and students in reading aircraft instruments ranged from 84.2 percent to 96.7 percent. Although the instruments were the typical three-pointer aircraft altimeters, Grether's work is important because it deals with 100 percent inspection of various numerical values which is similar to some kinds of inspection work such as dial and gage reading. Grether believes that these errors in "quantitative readings" are of two types, precision errors and interpretation errors. Precision errors arise from such factors as inaccuracy in interpreting pointer position between graduations, parallax, and poorly defined pointer and marking of the instrument. Interpretation errors, which are the kind that we wish to note, result from failure to interpret correctly what is actually seen. This portion of the errors which Grether noted is one that has quite an effect on inspector accuracy. Are persons engaged in an inspection task capable of seeing and then correctly interpreting what they have seen? Grether thinks not and suggests a need for further investigation in this area, because of the inconsistencies of accuracies in his and other (15) experiments.

The work of Sleight (27) and Thomas (29) is of interest also because it deals with the accuracy of persons inspecting simulated "moving" product, much the same as that found in continuous sampling situations. Sleight, through the use of

experimenter-paced (tachistoscopic) experiments determined that open-window dials, presenting one number at a time, at exposure time of .12 seconds, were read more accurately than round, horizontal or vertical dials. This dial reading procedure would be similar to an inspector's task of reading a size number or a serial number. Thomas later found that the real legibility of open-window dials was not the same at all exposure times, which would have an effect on how long an inspector should examine each attribute or each unit of product. His data showed the open-window dial to be second best to the horizontal dial at exposure times of .5 and .1 seconds. This interaction between dial shape and exposure time raises some question as to the validity of tachistoscopic methods of presentations. However, Kephart and Pecsok (22) have determined that there is no appreciable difference between tachistoscopic and subject-paced inspections at an exposure time of .2 seconds. These studies all conclude that there are differences in the accuracy of persons who perform inspector-type duties under various situations, and that these accuracies vary greatly.

Another problem which presents itself when we consider 100 percent inspection is that of vigilance, the situation where man is a monitor. How long can man inspect or examine product without succumbing to the effects of monotony, boredom, or fatigue? Automated systems are placing more and more demands on human operators, making accurate, error-free monitoring more important. Jerison and Wallis (20) and Buckner and McGrath (6)

found that individuals perform well for relatively short periods of time, but then the level of accuracy drops somewhat, and then remains relatively constant. They also found quite a number of individual differences in accuracies, leading them to believe that testing procedures may be used to select better performers.

Deese (9) bases his ideas of vigilance on the principle that the maintenance of a given level of vigilance in an observer depends to some extent on stimulus events extrinsic to the observer. He also states that when the stimuli are farther apart time-wise, vigilance declines, and so he maintains that the accuracy of the vigilance task is better when the presentations or targets per unit time are presented at a higher rate. Deese does agree with Jerison and Wallis (20) in the advocation of training for individuals who expect to be engaged in inspection or other decision-making situations of that type. Broadbent (5) also supports this. He suggests that the human nervous system would not be capable, through limitations of size, of simultaneously analyzing all the information received by its sense organs. He further states that it is not unreasonable to suppose that only a portion of any information given to a subject is analyzed at one time, that is, that only one part of the stimulation present is capable of initiating complex responses at a given instant. If any stimulus is to produce any response, he continues, it must possess marked advantages over all competing stimuli. Broadbent concludes by stating a fact particularly applicable to industrial inspection tasks similar to

those found in continuous sampling plans, that the pacing of an inspection process by a machine may prevent the inspector from shifting his attention momentarily from time to time, thus contributing to the inspector's apparent fatigue over extended studies or inspections.

Because of their basic nature and their relationships to the phenomena of sight and reaction to what is seen, these experiments in the field of psychology relate very well to the problems of why inspectors may or may not be "accurate" at their tasks. However, these studies, except that of Adams (1), relate their results to measures of visual acuity and visual aptitude tests, and so are not directly useful in the assessment of the accuracy of industrial inspectors during their work. (Adams has demonstrated the accuracy of agricultural technicians at separating wheat kernels, but, although he has an excellent statistical design and analysis, his results are not directly of value either. He has dealt with the complexities of color and physical properties of agricultural products, not with inspection of a single attribute of manufactured product.) Psychologists have not actually taken the problem of industrial inspector accuracy directly in hand, but have stated hypotheses which may or may not be applicable, depending on the particular industrial situation to which they might apply.

Keeping in mind the fact that all of the previously mentioned experiments are pertinent to a degree, let us examine what work has been done in the field of inspector accuracy by industrial personnel.

Industrial experiments in the area of inspector accuracy also disagree upon what factors have an effect on and what seems to be a reasonable accuracy level for various tasks of 100 percent inspection.

At the Western Electric Hawthorne Plant, the opinion was that inspectors were entirely correct or 100 percent accurate 95 percent of the time. However, an experiment by Jacobsen (19) proved otherwise. The task in the experiment was to inspect loose solder joints where one in 10,000 loose connections was non-conforming. Thirty defects were "seeded" in 1500 connections and 17 inspectors were tested. Jacobsen found, with accuracy measured by the percentage of defects correctly identified, that accuracy was 80.5 percent. For wiring and appearance defects, this percentage ranged from 32.0 percent to 65.0 percent. Jacobsen then ran another experiment using 39 inspectors and found that their accuracy, again measured by the percentage of defects correctly identified, was 82.2 percent. He further analyzed his data and found that four inspectors were 100 percent accurate and that one was only 45 percent accurate. He also determined that defects among solderless connections were found 84 percent of the time, while loose connections were found 82 percent of the time. Jacobsen further determined that there was no correlation between age and accuracy and that there was only a slight relationship between accuracy and visual acuity, as measured by the Standard Vision Orthorater.

In a second study, Jacobsen used four measures of inspector accuracy. These measures were percent of correct classification

of the total product, percent of correct classification of the satisfactory product, percent of correct classification of the defective product, and the increase in the percent satisfactory product as a result of inspection (expressed as a percent of the maximum possible improvement). Carter (7) as summarized in McCornack (25) also used these same four comparisons in a study of the accuracy of visual inspection of acoustical tiles. These tiles were inspected for fabrication defects, coating, cutting, drilling, and beveling. The inspectors correctly identified 95 percent of the good tiles, and rejected only 76 percent of the defective tiles. The tiles were submitted to the inspectors as 86 percent good and were found to be 96 percent good after inspection. The ten percent improvement was 71 percent of the maximum available improvement. The main faults of Carter's experiment were that neither the number of inspectors nor the number of tiles inspected was given. Neither Carter nor Jacobsen used any statistical methods other than raw percentages.

The four measurements used by Jacobsen and Carter as summarized by McCornack are given in the following table, along with the results of each experiment.

Table 1. Inspector Accuracies

Type Inspection	No. Units	No. Inspectors	A1	A2	A3	E
Solder Joints	1500	17			.805	
(Jacobsen)	1000	39	.996	.999	.828	.730
Surface Appearance (Carter)	?	?	.930	.950	.760	.710

Table 1 (concl.)

A1 = Percent of correct classification of the total product

A2 = Percent of correct classification of the satisfactory product

A3 = Percent of correct classification of the defective product

E = Increase in the percent satisfactory product as a result of inspection (expressed as percent of maximum possible improvement)

A more complete summary, with reference to other industrial studies, may be found in McCornack (25). Included is an experiment on the inspection of surface defects of piston rings. Some 40 defective rings were inspected by seven engineers and supervisors, and 67 percent of the defective rings were correctly identified. A second lot of rejected rings was inspected by the same inspectors and 67 percent of the rings were accepted. Since the inspectors had believed this lot to be reworked, another lot believed not to be reworked was submitted and this lot yielded 64 percent defectives correctly identified. Of interest in this experiment is the inspector's attitude; if he believes the product to be good, he will miss a good many defects. Several other studies are presented, having to do with visual inspection of various units, such as tin plates, yarn cones, sheets of wood veneer, and ampoules. Although these studies are of 100 percent inspection activities, these are all very vague as to measurement criteria, number of inspections, number of inspectors, and number of units inspected.

The current data on the accuracy of inspectors during the task of 100 percent inspection is quite varied. The experiments

which deal with psychological data gathered mostly under laboratory conditions, are statistically well-designed and analyzed, but we find that the psychologists have paid little attention to the industrial applications of the accuracies they have determined. The industrial studies, although applicable to special situations, are neither well-designed nor are they analyzed through the use of statistical methods. They involve little or no consideration of the psychological factors that are present. Throughout these studies, both the psychological and industrial, we find no adherence to a common measure for the accuracy of the inspectors.

It was for these reasons that this study was undertaken. The need has been noted for a technique to measure the accuracy of inspectors. This technique would take into account both the industrial and psychological aspects of the inspection task, and would utilize a well-designed and analyzed statistical method. The technique could also be used by industry to determine a basis for the accuracies of inspectors at various inspection tasks.

The development of this technique, an application and the results occupy the remainder of this thesis.

DEVELOPMENT OF A TECHNIQUE FOR DETERMINING INSPECTOR ACCURACY

Some Salient Features

A review of the current literature on the accuracy of inspectors during the task of inspection of attributes cites the need for a technique to determine inspector accuracy which would include both the industrial and psychological aspects of the inspection task (25).

For the purpose of accounting for these aspects, the technique in this thesis was one which could be easily duplicated in industry or in the laboratory for use in determining inspector accuracy. For this reason this technique used standard industrial instruments which featured a psychologically designed presentation (14). This technique involved inspector recognition of one attribute at a time, so that a basic accuracy could be determined; this was accomplished by the presentation of individual attributes in the form of one-digit random numbers to the inspector. This simulated one of the most simple attributes inspection tasks. This technique also involved an inspection task representative of those found in actual industrial situations by using random time intervals and fixed time intervals between presentations. Finally, this technique utilized a statistical design and analysis which allowed proper and sufficient data to be gathered for the purpose of determining factors that contribute to the accuracy of inspectors during the task of attributes inspection.

The development of a technique for the determination of inspector accuracy during inspection of attributes follows in this section.

The Experiment

The purpose of this experiment was to investigate a technique which may be useful in determining the accuracy of industrial inspectors at the task of inspection of attributes, utilizing a method of visual identification and notation of randomly originated one-digit numbers, presented at both random time intervals and fixed time intervals.

The task of visual inspection is done by an inspector during almost every inspection task he undertakes. When the inspector is engaged in 100 percent inspection of attributes in a continuous sampling situation, he examines each piece of product as it is brought to him. For example, he inspects products arriving at the inspection station on a conveyor belt or brought by some other method affording continuous presentation. This type of inspection task may be compared to either fixed time intervals between presentation of product units or random time intervals between presentation of product units, depending on the process characteristics. Also, when the inspector is engaged in inspection of each unit of a representative sample of units from a production lot, as in acceptance sampling of attributes, he may inspect the sample at a fixed-interval rate between units, or, because he probably will not accurately pace himself so as to assure a fixed interval, he may inspect the sample at a random interval rate between each unit of product. There are, then,

two possible ways in which the inspector may visually inspect each product attribute, either at fixed intervals between units, or at random intervals between units, depending on the process and also depending upon the inspector's own habits of inspection.

It may be asked whether or not one method of presentation of product units for inspection is better than the other. Are inspectors more accurate at 100 percent inspection when product is presented at fixed intervals so that a rhythmic anticipation by the inspector can contribute to this accuracy? Are randomly spaced presentations, where the constant attention of the inspector is needed throughout the inspection task, better because of the continuous attention required? In order to consider this problem fully, it is well to be aware of three factors. These three factors are the duration of each individual presentation, the average interval between presentations, and the overall duration of the inspection task.

The duration of each presentation refers to that length of time for which the attribute to be inspected is made available to the inspector for the purpose of examination. This length of time must be at least the minimum time to include recognition of the attribute, a decision by the inspector as to whether the attribute is of a "go or no-go" nature, and an action time of either writing down the condition of the attribute, removing the part from those being inspected, or some other action signifying the status of the attribute in question. Minimal muscular reaction times to visual stimuli are presented by Luckiesh and Moss (24) with the average time being .189 seconds. This would indicate a guide or base presentation time below which the

experimenter must not venture for fear of introducing the problems of minimum thresholds. To reduce the number of variables to be considered during this experiment to only the important ones for this purpose, one time was determined for the duration of the presentation and was used consistently. In order to compare the results of this experiment to those of Grether, Kephart and Pecsok, and others (6) for the purpose of justifying our results, the presentation time, or the duration for which each attribute is available for inspection was set at 1.5 seconds. This time was considered to be well above the minimum time for reaction and was also considered to be of magnitude so that the final results as to the accuracy of the subjects could be favorably compared to those studies already done in this area.

The average interval between presentations refers to that length of time from the cessation of the previous attribute presentation to the instant the next attribute is presented, assuming that the inspector does not have to search for the attribute to be examined. Deese (10) has referred to this factor as the average targets per hour. Through experimentation, he has determined that as the average number of targets per hour increases, the number of the observer's correct decisions as to the condition of targets also increases. It has been stated that the number of targets per unit time (attributes) presented for inspection varies with process, but will be either a fixed interval or a random interval time between units. Since it was desired to determine inspector accuracy at both fixed and random interval tasks, included in the statistical design is a method by which one may check the accuracy and also check the effect of

one type of presentation upon the other. One limitation however, was the average number of presentations or targets per unit by the emission rate characteristics of the radioactive source. This rate was analyzed for randomness and found to be acceptable at an average rate of three presentations per minute or 180 presentations per hour.[1] This source was mounted in the random interval pulse generator and used to provide attributes of a random nature for the random interval portion of the experiment. In order to compare inspector accuracies at both the random and fixed interval tasks, the fixed interval pulse generator was also set to present 180 attributes in the form of random numbers per hour. In this way, the accuracies of subjects at the task of 100 percent visual inspection of attributes could be easily compared using our experimental design.

The overall duration of the inspection task refers to the length of time the inspector spends on the job between periods of no inspection. Various studies on the problems of vigilance, or man's ability to be a monitor have been made (5). Rather than attempt to account for various degrees of decrement in this experiment, the length of each inspection task in this experiment was ten minutes. This task length compares favorably to the work done on monitoring by Hardesty and Trumbo (18), and provided data from each subject on an average of 30 inspections for the ten minute task. This same length of presentation and average number of presentations was the same for both the fixed and the random interval inspection tasks.

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[1] Research by J. V. Poola, Department of Industrial Engineering, Kansas State University.

Using a presentation time of 1.5 seconds, an average number of 30 presentations per task duration of ten minutes, at both a random and a fixed interval rate, this experiment was conducted using the following statistical design and experimental conditions.

The Statistical Design

The attributes to be inspected in this experiment for the purpose of determining the accuracy of inspection were random numbers generated by the Beckman Timer. The Beckman Timer measured the duration between each presentation to the .00001th decimal place, and because of the characteristics of this duration, this N was considered to be the nearest to a pure random number available from this experiment.

The experimental design utilized for this experiment was a two-factor design with repeated measures on one factor. The treatments for this experiment consisted of the two methods in which the attributes to be inspected were presented, fixed intervals between presentations and random intervals between presentations (designated B). The order in which these treatments were presented was used to compare whether or not one order of presentation or the other had any effect on the accuracies of the inspectors (designated A). The subjects were divided into two groups of 15 inspectors each, grouped randomly and designated as G-1 for group 1 and G-2 for group 2. In this experiment, the subjects were nested within the groups, or orderings, and they were crossed with the treatments, fixed intervals followed by random intervals and then random intervals followed by fixed intervals. The treatment to be presented to the inspectors was

determined randomly and the fixed interval was presented to group 1 first. The experimental design and the analysis of variance table are found in Winer (32), pages 302 to 307.

Through the use of this statistical design, it was possible to test several hypotheses as to what factors have an effect on inspector accuracy during the task of 100 percent inspection of attributes. These hypotheses were checked for significance through the method of the F-tests shown in the Expected Mean Squares column. These tests were made under the assumptions that the distributions of the means in each measurement were normal, independent, of mean equal to zero and of variance σ^2, (NID, $0, \sigma^2$). In all three of the F-tests the test was for $\mu_1 = \mu_2$ or $\mu_1 - \mu_2 = 0$; in other words, the test was to see if the means were or were not significantly different, using a confidence level of 95 percent.

The null hypothesis (H_{01}) in F-test number 1 (F_1) was that there was no significant difference in the means due to the ordering of treatments among the subjects. The alternative hypothesis (H_{A1}) was that there was a significant difference, that there was an effect on the accuracy of the inspectors due to the ordering of treatments (presentations).

The second F-test (F_2) allowed the determination of any interaction or possible joint effects of the two variables, order and treatment. H_{02} was the null hypothesis to test for no significant joint effect; H_{A2} was to test any joint significance. This F-test was for the purpose of determining whether any combination of order and treatment had a distinct effect on the inspector's accuracies.

The null hypothesis (H_{03}) for the third F-test (F_3) was that there was no significant difference in the means of the accuracies due to the effects of the treatments themselves, i.e., there was no difference in the accuracies between inspection of fixed interval presentations and random interval presentations. H_{A3}, the alternative, was that there was a significant difference due to treatments.

Subjects

The subjects for this experiment were 30 volunteer undergraduate Industrial Engineering students from Kansas State University. These men were used due to an absence of industrially trained inspectors. It was felt that the familiarity of these men with the number system used to simulate the attributes for inspection would serve the purpose of this experiment.

These men were still under the "student incentive" to do well at a given task. It was further noted that since they had no prior industrial inspection experience, these subjects would not contribute the inspector bias phenomena of "curtailment" mentioned by McCornack (25) and Juran (21). This phenomena contributes to the inaccuracy of inspection personnel in that the inspector "finds" defects in order to increase his accuracy. Since the subjects for this experiment were not concerned with this phenomena, there was little tendency for any of them to call one number-attribute another, except on a chance basis.

For these reasons, it was felt that the inspection accuracies of these subjects would be determined solely by their chance errors, which is what this experiment concerned.

Apparatus

The equipment used in this experiment consisted of a random interval pulse generator, an exact interval pulse generator, a Beckman interval timer, a Beckman tape printer-recorder, and a Hughes standard work station (see Plates I and II).

The random interval pulse generator operates by utilizing the principle that radioactive material emits alpha-particles at time intervals that approach a normal distribution (8). The material used for the emission of alpha-particles during this experiment was uranium. The uranium sample was mounted in such a way as to permit a proportional counter tube, similar to the type used in Geiger counters, to accept an entering alpha-particle, which caused the tube to emit an electronic pulse. This pulse was magnified within the generator, and then transmitted to the Beckman timer. The rate at which the alpha-particles enter the tube was varied by changing the concentration of the radioactive material.

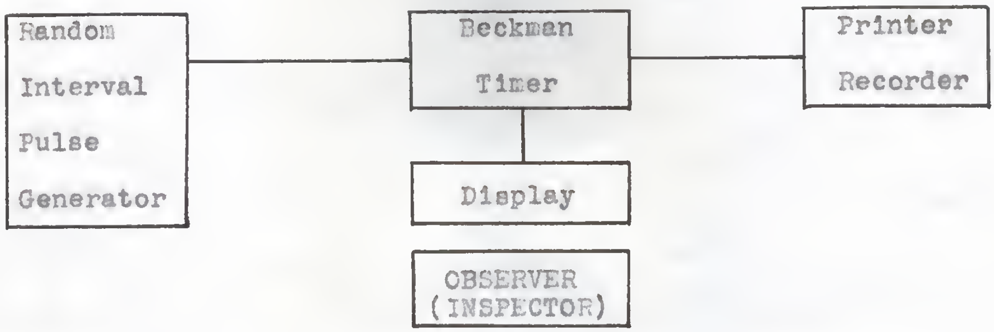
The exact interval pulse generator functions by means of a voltage source connected to a capacitor, these being in a circuit with a battery and a relay. As the battery controls the relay pulses, the capacitor is alternately charged and discharged. By varying the charge and discharge times of the capacitor, the length of times between charges can be varied

EXPLANATION OF PLATE I

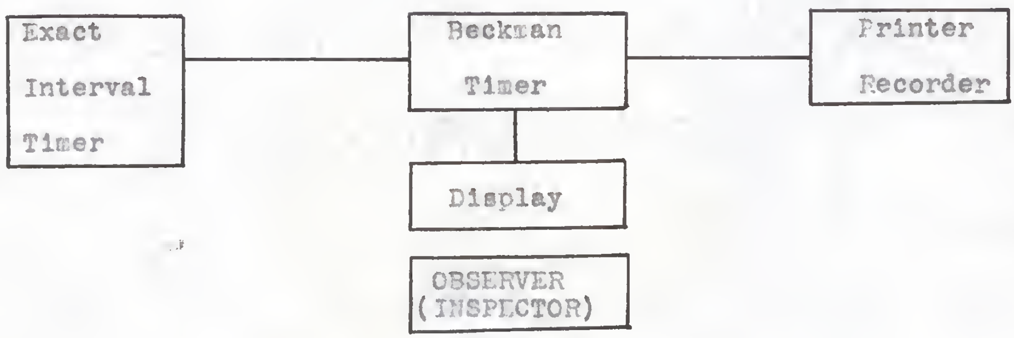
Upper schematic represents instrument arrangement and inspector position during presentation of random number attributes at random intervals.

Lower schematic represents instrument arrangement and inspector position during presentation of random number attributes at fixed intervals.

PLATE I



Instrument Arrangement for Presentation of
Random Number Attributes at Random Intervals



Instrument Arrangement for Presentation of
Random Number Attributes at Fixed Intervals

EXPLANATION OF PLATE II

Upper Photograph

Equipment utilized in the experiment:

A Random Interval Pulse Generator

B Fixed Interval Pulse Generator

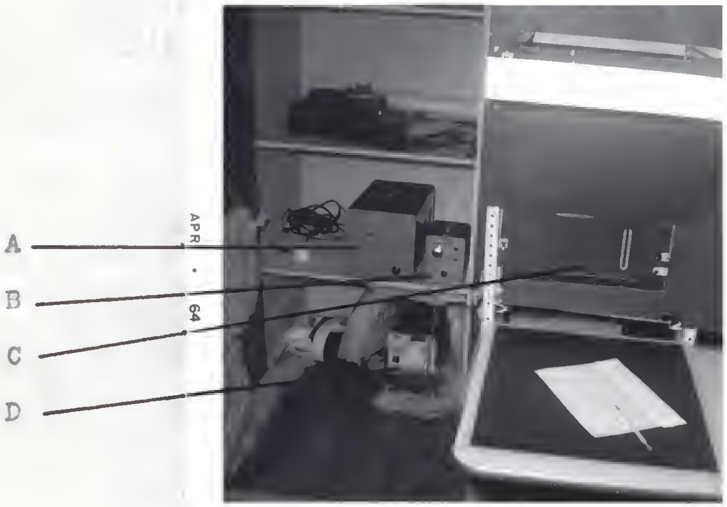
C Beckman Timer

D Beckman Tape Printer-Recorder

Lower Photograph

A subject wearing earphones shown at the inspection task. Shows the inspector, workplace, data presenting column and supporting equipment. (Both interval generators and the printer were closed in the cabinet during trials.)

PLATE II



from two seconds to 600 seconds. The length of the discharge time can be varied from .5 seconds to eight seconds. With the discharge function connected to the Beckman timer, the display time of any number can be controlled and the length of time between displays may also be controlled.

The Beckman timer is an electronic counting device, and, when put in the circuit with either the random or the exact interval pulse generator, displays any number or series of numbers in any or all of the six vertical windows on its face. These displays of numbers are dimly lit while the unit is counting. Then, when an impulse is sent to the timer, all the numbers except the number specifically designated to the timer black out. Thus, if the number 5 were transmitted, columns (vertical displays) 1 through 5 (from left to right) would go black, except for a zero at the bottom of each, and the number 5 would appear white against a black background in column 6. The dimensions of these numbers for the purpose of experimental instrument reading agree with Fogel (21) and the columns may be set to any decimal place reading from 000000.0 to 0.000000.

The Beckman tape printer-recorder is a number printing device which, when coupled to the Beckman timer, will record any number signal transmitted to the Beckman timer, as the timer displays it. Any or all of the numbers displayed by the timer will be printed on a tape by the printer. The printer was equipped with a remote switch so that the experimenter could control the printer and not disturb the subjects at the inspection task.

The Hughes standard work station was developed for use with audio-visual instruction equipment to be used by persons engaged in industrial assembly and inspection tasks. It consists of a formica table at lower than elbow level, a stool with a seat and seat back and a fluorescent lighting fixture which provides 16 foot candles of non-glare light at the working surface of the table. This work station was designed to be easily adapted to the principles of motion economy. It was also felt that this workplace would represent a typical industrial inspection environment (see Plate 2).

Conduct of the Experiment

The experiment was conducted in the Industrial Engineering Work Measurement Laboratory. Each subject was seated on the stool in front of the Hughes standard work station as shown in Plate 2. The subject was given a lined, two-column sheet of paper sans numbers and a pencil. He was then told the following instructions:

The purpose of this experiment is to determine the accuracy of individuals at the task of correctly reading and writing down numbers which will be presented to you on the vertical column dial before you. The numbers on the dial will remain lit dimly as you see them now until a predetermined signal causes them all to go out except the number you are to read and note. When the column goes dark like this (here the subject was shown two or three number presentations as they would appear during the trial), you will see one number (digit) brightly lit on the dial. You

are asked to note this number and write it down on this sheet. You are to note and write down each succeeding number in their order of presentation beginning at the top of the left column, proceeding to the bottom of that column and if more space is required, proceed to the top of the right column. You are to note and write all the numbers you see until the ten-minute trial is over. Please keep your eyes on the column at all times, as the numbers may appear at any time. Please do not talk or ask questions during this trial. I will tell you when to begin and when to stop. Do you understand what you are to do?

The subject was then asked to place the earphones on his head to keep out any outside noises. (It was noted during a pilot study that the subjects might be able to detect the noise of the printer and thus detect when he should look for a number in the column.) The subject was then told in a firm voice by the experimenter when to begin the task and, ten minutes later, when the task was finished. At the instant the subject was told he was finished, the experimenter turned off the Beckman printer with a remote switch so that the subject's results could be compared with the printed results.

At the end of the exercise, the subject was thanked and asked to return in five days if he still had the second trial yet to do. These same instructions and methods were used at each of the two trials.

The results of this experiment occupy the next section of this thesis.

RESULTS OF THE EXPERIMENT

The object of this experiment was to determine the accuracy of subjects at correctly recognizing and noting the random numbers presented to them at both random intervals and fixed intervals, and to determine if the technique utilized was of any value in determining this accuracy.

The subjects were tested in random order in each trial. Each set of a subject's written responses was compared to the accompanying printed results and an accuracy in the form of a percent was determined for each subject. The accuracies for each of the 15 subjects in each block of the statistical design were averaged, and this percent represented the average accuracy of inspectors at the designated tasks. Through the mechanics of the design, the following information was gathered:

1. The accuracy of the subjects (inspectors) at correctly identifying the random numbers was determined. This simulated the accuracy of inspection of attributes during an inspection task. The accuracy was determined as the percentage of correct responses made by the subject out of the total number of presentations shown. An error was classified as (a) signal not detected, (b) a signal incorrectly identified, i.e., writing a different number from the number presented, or (c) writing a number when no number was presented (25).
2. The effect and significance of presenting either the random interval numbers or the fixed interval numbers first was determined by the F-test, (F_1). If this test showed

significance, then the order in which the treatments were presented had an effect on the accuracy, and it would be concluded that the accuracy of inspectors was affected by the previous inspection task.

3. The interaction between the order in which the treatments were presented and the treatments themselves was tested by F_2. If the results of this test were significant, then it could be stated that the interaction had an effect on the accuracy of the inspectors. If this interaction is negligible, then the effect of the treatments alone on the inspectors is significant.

4. The effect and significance of the treatments, either random interval presentations or fixed interval presentations, on the inspectors was tested by F_3. This provided for the determination of whether or not the inspectors were more accurate at recognizing and noting random numbers at random intervals or at fixed intervals.

The accuracies of the subjects at the inspection task are shown in Table 2. Group 1, composed of 15 subjects, was presented the random numbers for inspection at fixed intervals during the first trial. The average number of presentations per inspector during the ten-minute trial was 31.9. (This decimal fraction of presentations was due to a slight instability in the signal generator which could not be overcome. Each subject was presented a whole number of presentations.) The total number of presentations made to the group was 479. There were no errors of any kind made by this group during this trial.

Table 2. Accuracies of subjects at the inspection task.

Subject Number	Group 1 (Fixed)	Group 2 (Fixed)	Group 1 (Random)	Group 2 (Random)
1	100.0%	100.0%	100.0%	93.8%
2	100.0	100.0	100.0	100.0
3	100.0	100.0	100.0	95.7
4	100.0	100.0	100.0	100.0
5	100.0	100.0	95.5	96.7
6	100.0	96.8	93.3	100.0
7	100.0	100.0	95.5	100.0
8	100.0	100.0	100.0	100.0
9	100.0	100.0	95.5	100.0
10	100.0	100.0	100.0	96.2
11	100.0	100.0	100.0	100.0
12	100.0	100.0	95.5	100.0
13	100.0	100.0	100.0	96.0
14	100.0	100.0	100.0	96.4
15	100.0	100.0	100.0	100.0
$\bar{X}$ =	100.0	99.8	98.4	98.3

	Fixed	Random
Pooled	99.89 = 99.9%	98.33 = 98.3%
$\frac{\text{Correct responses}}{\text{presentations}}$ =	99.89 = 99.9%	98.46 = 98.5%

Accuracy = total correct responses divided by total presentations to the group

$\bar{X}$ = Average accuracy of the group.

Therefore, the accuracy of Group 1 at the fixed interval trial was 100 percent as accuracy has been defined herein.

These subjects in Group 1 were presented the random numbers at random intervals five days after the fixed interval test. A different subject order was used for this trial. A total of 330 presentations was made to the subjects; the average number of presentations per subject was 22 for the ten-minute trial. The most presentations to one subject was 29 and the least was 12. (This difference in rates was due to the variation of the radioactive source. The source was standardized at 3.2 presentations per minute before the trials.) Ten of these subjects completed the task without any errors. Three of the subjects failed to detect one presentation each and two subjects incorrectly identified one presentation each. None of the subjects noted a presentation not given. In order to simplify statistical calculations, all the errors were grouped, making any and all errors equally significant. There was no pattern about these errors regarding where they occurred during the trial, as some appeared early, others late. The five subjects committing these errors were 95.1 percent accurate as a group. The average accuracy of the entire group of 15 was 98.4 percent. The average accuracy of the group for both the fixed interval and random interval tests pooled was 99.9 percent.

The 15 subjects in Group 2 were presented the random numbers at random intervals during the first trial. Subject order was random. A total of 334 presentations was made to the group, the average being 25.6 presentations for the ten-minute trial.

(This variation in presentation was again due to the randomness of the radioactive source.) The most presentations made to a subject was 32 and the least 16. Nine of the subjects achieved 100 percent accuracy. Six of the subjects erred, five failing to note one presentation each and one incorrectly identifying one presentation. None of these subjects noted a presentation not given. Again, all errors were grouped. There was no occurrence pattern of the errors. The average accuracy of the six erring subjects was 96.2 percent and the average accuracy of the entire group was 98.3 percent.

The subjects in Group 2 were presented the random numbers at fixed intervals five days after their previous trial. The 15 subjects were presented a total of 477 presentations. The average number of presentations for the ten-minute trial was 31.8 (again due to the slight instability of the instruments). Fourteen of the subjects achieved 100 percent accuracy. One subject failed to note one presentation, thus making his accuracy 96.8 percent. The average accuracy of the group was 99.8 percent. The group accuracy for both trials was 98.5 percent.

The data in Table 2 from the experiment were placed in the following summary table of the accuracies:

Table 3. Summary of accuracies.

Presentations	Fixed Intervals	Random Intervals
Fixed, then Random (Group 1)	100.0%	98.4%
Random, then Fixed (Group 2)	99.8%	98.3%

Group 1 was 100 percent accurate at inspection of the fixed interval presentations and 98.4 percent accurate at inspection of the random interval presentations. Group 2 was 99.8 percent accurate at inspection of the fixed interval presentations and 98.3 percent accurate at inspection of the random interval presentations.

The data in Table 2 were then coded for ease of calculation (see Appendix) and placed in the following analysis of variance table for testing of the three null hypotheses:

Table 4. Analysis of variance (32) using coded data.

Source	Degrees of Freedom	Sums of Squares	Mean Squares
Order (A)	1	.23	.23
Subject;Order	28	37.05	1.32
Treatments (B)	1	36.35	36.35
A X B	1	.12	.12
B X Subjects within Groups	28	126.61	4.52
	59	200.36	

The F-tests are as follows:

$$F_{1(1,28)} = \frac{.23}{1.32} = .17 < F_{(1,28,.05)} = 4.20$$

$$F_{2(1,28)} = \frac{.12}{4.52} = .03 < F_{(1,28,.05)} = 4.20$$

$$F_{3(1,28)} = \frac{36.35}{4.52} = 8.04 > F_{(1,28,.05)} = 4.20$$

$$F_{3(1,28)} = 8.04 > F_{(1,28,.01)} = 7.64 \quad (13).$$

The null hypothesis (H_{01}) tested by the F_1-test was that there was no significant difference in the means of the accuracies due to the ordering (fixed interval then random interval or random interval then fixed interval) of the presentations. The alternative hypothesis (H_{A1}) is that there was a significant difference due to ordering. This F-test indicated that there was no significant difference at 95 percent confidence level in the means due to ordering ($F_{(1,28)} = .17 < F_{(1,28,.05)} = 4.20$).

The null hypothesis (H_{02}) tested by the F_2-test was that there was no significant difference in the means due to the interaction or joint effects of the two variables, orders and treatments. The alternative hypothesis (H_{A2}) was that there was effect due to interaction. This F-test indicated that there was no significant effect at 95 percent confidence level on the means of the accuracies due to interactions of the two variables ($F_{(1,28)} = .03 < F_{(1,28,.05)} = 4.20$).

The null hypothesis (H_{03}) tested by the F_3-test was that there was no significant difference in the means of the accuracies due to the effects of the treatments themselves, i.e., there was no difference in the accuracies of the inspectors at the task of inspecting fixed interval presentations and random interval presentations. The alternative hypothesis (H_{A3}) was that there was a significant difference due to the difference in the treatments at the 95 percent confidence level.

This test indicated significance and supported the alternative hypothesis (H_{A3}) that there was a difference in the mean accuracies of the inspectors due to the difference in the

treatments at the 95 percent confidence level ($F_{(1,28)} = 8.04 > F_{(1,28,.05)} = 4.20$). This agrees with the data in Table 2, which shows that only one subject in 30 made an inspection error during the fixed interval presentation trials, but 11 subjects of the 30 each made one inspection error during the random interval presentation trial. A further F-test showed significance at the 99 percent confidence level ($F_{(1,28)} = 8.04 > F_{(1,28,.01)} = 7.64$). This indicated that at the 99 percent confidence level, the means of the accuracies differed. Stated another way, there is less than one chance in 100 that the means of the fixed interval accuracies and the random interval accuracies would be equal.

The results of this experiment demonstrated several interesting facts about inspector accuracy at the given task.

The experiment showed that inspectors are not 100 percent accurate at the task of recognizing and noting one digit random numbers at both fixed intervals and random intervals for periods of ten minutes. This agrees with the summary of literature of inspector accuracy by McCornack (25) and others (18, 19). The research also showed that inspectors are apt to be more accurate at inspecting one digit numbers when the numbers are presented at random intervals. This agrees with results determined by Buckner and McGrath (6).

The research also showed that there was no interaction between the treatments and their order which affected the accuracy of the inspectors during this experiment, nor was there any effect on accuracy due to ordering of the treatments themselves.

These results showed that even for periods of time as short as ten minutes, inspectors who are required to recognize and note one digit random numbers, such as those presented by the industrial process monitoring device simulated herein, are not 100 percent accurate in every task instance.

SUMMARY AND CONCLUSIONS

The purpose of the research in this experiment was to determine the accuracy of inspectors at recognizing one digit number attributes, presented at fixed intervals and random intervals, and writing them down. This experiment demonstrated that the subjects as inspectors of one digit numerical values were not 100 percent accurate.

This test was similar to many industrial inspection tasks. The significances of this research as it applies to these industrial inspection tasks are manifold. In view of the fact that few well-designed, analyzed, and reported studies have been made of inspector accuracy to date, the factors which this research reports may be applicable to industry in varying degrees depending upon how they are applied to specific inspection situations.

The first significant factor of this research was that the inspection task performed by the subjects simulated an actual industrial inspection situation in that it required the subject to recognize and make note of individual numerical values. Many inspection tasks involve this recognition of one digit numbers in the manner of the experiment, some examples being readout of electronic instruments monitoring processes, electronic sorting devices, computer consoles, and other instruments which present data for inspection utilizing one digit presentations. Studies of industrial inspector accuracy as summarized by McCornack (25) present research on inspection tasks of an attributes nature, but involve inspection of solder joints, yarn cones, tin plates, and

tasks other than readout of numerical values. The only numerical recognition tests which McCornack notes are those involving vernier micrometers, and these did not deal with recognition of one digit numbers specifically.

Studies by psychologists (6) in the areas of monitoring performance and vigilance indicate that the subjects used as inspectors were required to recognize the presence of a point source of light only; they were not required to define the condition of the light (state whether it was a number or letter or give a value), but were only required to state if they did or did not see the light source. Other studies by Hardesty, et al. (18) required the inspector to detect a double jump of clock hands on a blank face. Again, no numbers were presented in the Mackworth study.

A second significant factor of this research was that the instrument used to present the numbers to the subjects, the Beckman interval timer, was designed especially for good, clear, "human engineered" presentation of data as compared with data in Fogel (14). The shape of the digits, the lighting method, and the methods of presentation (fixed intervals between signals and random intervals between signals) made the task of reading the presented data comparable to industrial inspectors' tasks of reading single digit values from many presently used monitoring instruments in industry. An example of this type of instrument is the Accurate Electronics Automatic Cable Tester (3) which measures the insulation resistance, dielectric strength, and the continuity of electric cable as it is processed. Another

example is the Laboratory for Electronics Line Voltage Monitor (23) which automatically reads and presents line voltage changes in electronic equipment as it operates. This instrument is equipped with Beckman-type vertical columns for presentation. Still another example is the task requiring readout of the dial of "real time" values between incoming data impulses on console of Automatic Electric's computer console (4). The control console is designed to allow the operator to monitor operations, and thereby control the system without a detailed knowledge of computers.

The examples of equipment just shown point out the need for this type of experiment, which dealt with accuracy of inspectors at the task of reading and noting values presented by means of modern electronic monitoring instruments.

A third significant factor of this research was that it utilized a statistical design and analysis to determine the effects of the various orderings of presentations, the effects of the treatments and any interaction that might have occurred. Psychologists have utilized statistical design for quite some time in almost all studies of accuracy. Industrialists have done little more than use raw percentages to report their data. This thesis partially fills the gap between the two groups primarily concerned with inspector accuracy in this respect. This research combined previous psychological and industrial techniques, plus a statistical model to determine what one of the factors is that affects the accuracy of industrial inspectors.

The last, and probably most significant factor of this research is that the results proved to be consistent with previous experimental results, even though the experiment utilized a somewhat different technique of determining the accuracy values. McCornack (25) has concluded that industrial inspector accuracies range from 99.9 percent at some tasks to negative values for others. A review of the literature available on studies by psychologists has also yielded a wide variation of accuracy values. The fact that accuracy varies with the signal presentation rate was found to be the only statistically significant factor in this experiment, and this agrees with other studies by Buckner and McGrath (6).

From a theoretical viewpoint, this research agrees with previous studies by psychologists and industrialists as to the fact that inspectors are not 100.0 percent accurate and that the rate of presentation of signals affects the inspectors' accuracy. From a practical application standpoint, this research utilized an instrument very similar to many industrial monitoring instruments. This research, therefore, has additional information applicable for both psychologists and industrialists, to the field of studies of inspector accuracy.

There were some factors about this experiment and the procedure used that were not consistent with past experiments. The duration of each presentation was 1.5 seconds, which was determined to be a value above visual threshold limits (24). Other than that, it was an arbitrary value, determined by the limiting characteristics of the electronic equipment used in the

experiment. The time between each presentation and the duration of each presentation were difficult to control because of the instability of the equipment and the radioactive source. Further research and work on the apparatus might provide means for better control of these values.

The purpose of this research was to investigate inspector accuracy at a task representative of several industrial inspection tasks. The method used in the experiment was unique, but still determined that inspector accuracy is not 100 percent in every instance.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the faculty, staff, and students of the Department of Industrial Engineering for the aid given in connection with the preparation of this thesis. The advice, aid, and continual guidance of his major professor, Mr. P. M. Wallack, have been of great value throughout the development of this thesis. The writer also wishes to acknowledge the aid of Dr. A. M. Feyerherm on the statistical problems in this research.

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APPENDIX

Accuracies of Subjects from Table 2
(Coded by subtracting 93.3 from each entry)

Subject Number		Group 1 Fixed	Group 2 Fixed	Group 1 Random	Group 2 Random
1		6.7	6.7	6.7	.5
2		6.7	6.7	6.7	6.7
3		6.7	6.7	6.7	2.4
4		6.7	6.7	6.7	6.7
5		6.7	2.2	6.7	3.4
6		6.7	0.0	3.5	6.7
7		6.7	2.2	6.7	6.7
8		6.7	6.7	6.7	6.7
9		6.7	2.2	6.7	6.7
10		6.7	6.7	6.7	2.9
11		6.7	6.7	6.7	6.7
12		6.7	2.2	6.7	6.7
13		6.7	6.7	6.7	2.7
14		6.7	6.7	6.7	3.1
15		6.7	6.7	6.7	6.7
$\bar{X}$	=	6.7	5.1	6.5	5.0
$\Sigma(X^2)$	=	673.35	468.26	640.71	446.89

*Summary of Table 3 (Using coded data).

Presentations	Fixed Intervals	Random Intervals	Sums
Fixed, then Random (Group 1)	100.5	75.8	176.3
Random, then Fixed (Group 2)	97.3	75.3	172.6
Sums	197.8	151.1	348.9

*Table 3 shown in the text of this thesis is the sum of the coded data.

Calculations for Anova

Correction Factor = $(100.5 + 75.8 + 97.3 + 75.3)^2 = 2028.85$

Total Sum of Squares = $\left[(673.35 + 468.26 + 640.71 + 446.89) - 2028.85\right] = 2229.21 - 2028.85 = 200.36$

Treatment Sum of Squares = $\dfrac{(197.8)^2 + (151.1)^2}{30} - 2028.85 = 36.35$

Order Sum of Squares = $\dfrac{(176.3)^2 + (172.6)^2}{30} - 2028.85 = .23$

Treatments X Orders = $\dfrac{100.5^2 + 75.8^2 + 97.3^2 + 75.3^2}{15} -$

$36.37 - .23 = .12$

Subject:Order = $\left[(6.7 + 6.7)^2 \cdots\cdots (6.7 + 6.7)^2\right] - 2029.08 = 37.05$

B X Subject:Groups = by Subtraction = 126.61

AN INVESTIGATION OF INSPECTOR ACCURACY
AT THE TASK OF RECOGNIZING RANDOM NUMBERS

by

GEORGE PAUL DOBSON

B. S. Kansas State University, 1961

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1964

The object of this research was to investigate a technique which may be useful in determining inspector accuracy at the task of inspection of attributes. This technique utilized a method of visual identification of randomly originated numbers presented at both random time intervals and fixed intervals.

A review of the literature on the accuracy of industrial inspectors showed a wide variation in inspector accuracy at different tasks. It was also noted that few experiments had been well-designed and analyzed statistically and many had incompletely reported the factors involved. One task for which accuracy figures were not available was that of inspecting industrial monitoring devices for periods of ten minutes.

A method of presenting random numbers at both fixed intervals and random intervals was developed. This method utilized a radioactive source to develop the random intervals and an instrument which presented one-digit numerical values, similar to several instruments used to monitor industrial processes.

The experiment was conducted using engineering students as inspectors, each inspector spending two ten-minute trials at the test. One group of 15 inspectors was presented the random numbers first at random intervals and then at fixed intervals. A second group of 15 was presented random numbers at fixed intervals first and then random intervals.

The design of the experiment provided for the determination of whether or not the order of the treatments, the interaction between order and treatments, and/or the treatments themselves had any effect on the inspector accuracy. The results showed

that the only factor which had any effect on the accuracy was the treatments. The inspectors were significantly more accurate at reading and noting the fixed interval presentations than they were at reading and noting the random interval presentations. The pooled data showed 30 inspectors to be 99.9 percent accurate at the fixed interval task and 98.5 percent accurate at the random interval task.

The results of this experiment agreed with results found in experiments performed by psychologists and industrialists showing that 100.0 percent accuracy is difficult to attain, even at the most simple inspection tasks.

Some important factors of this research are:

1. It simulated an actual industrial inspection situation;
2. The instrument used to present the random digits was representative of industrial monitoring equipment;
3. A statistical design was used to analyze data recorded;
4. All pertinent data was completely recorded and reported.

The slight instabilities of the electronic equipment used, the duration of each presentation, and the time between presentations may contribute to some inconsistencies when these results are compared to those of other experiments. However, it is felt that these conditions did not detract from the value of the study, which contributed a needed addition to research on the determination of inspector accuracy.